ABSTRACT

Air Pollution: Household Soiling and Consumer Welfare Losses

by

William D. Watson

John A. Jaksch

This paper uses demand and supply functions for cleanliness to estimate household benefits from reduced particulate matter soiling. A demand curve for household cleanliness is estimated, based. upon the assumption that households prefer more cleanliness to less. Empirical coefficients, related to particulate pollution levels, for shifting the cleanliness supply curve, are taken from available studies. Consumer welfare gains, aggregated across 123 SMSA's, from achieving the Federal primary particulate standard, are estimated to range from $.9 to $3.2 million per year (1971 dollars).

DISCLAIMER

Draft: HES Disc #8

Air Pollution: Household Soiling and Consumer Welfare Losses

by

William D. Watson and John A. Jaksch

Introduction

Passage of the Clean Air Act of 1970 has brought about a substantial reduction in the emissions of particulate matter from fuel combustion and industrial processes. Control of these emissions has been costly. While there is evidence that societal benefits--such as- improvements to human health, reduced crop damage, cleaner households--have accrued as a result of the Act's passage, one may legitimately ask if the costs of complying with the Act exceed the benefits.' This is a progressively more urgent question at both national and local levels as one considers the energy crisis, inflation, and the increasingly high costs of meeting government mandated regulations.

This paper focuses on developing a rationale and model for economically quantifying societal benefits from control of particulate emissions as reflected in increased household cleanliness. The methodology is designed to address the following questions: (1) What is a logically consistent method for calculating gains in household welfare due to increased cleanliness from reduced particulate air pollution? (2) By how much are households likely to benefit as Federal primary and secondary 'standards for particulate matter are achieved? (3) How might these estimated gains in societal benefits affect particulate control policies?

This paper does not represent the first attempt at quantifying the effect of particulate matter on household cleanliness and welfare.' However, the approach described in the paper recognizes and overcomes two major shortcomings inherent in the previous works. First, our approach compensates for attitudes toward cleanliness. With the exception of Ridker's study [19], none of the previous studi'es attempted to correct for attitudes toward cleanliness. Tastes for cleanliness can affect housekeeping behavior. Meticulous households may clean more frequently and react more strongly to pollution than lackadaisical households, _ceteris paribus_. This analysis classifies households according to preferences on cleanliness and uses the information to estimate cleaning frequencies and household cleaning cost. Second, our approach estimates demand and supply curves for household cleanliness. _This different approach in methodoloqy is very important_. Previous studies incorrectly measured changes in welfare from pollution soiling as being equal to estimated changes in cleaning expenditure as affected by pollution. But, as we show, cleaning expenditure is only one input into the correct estimation of welfare changes.

In general, to estimate changes in household welfare, it is necessary to measure demand and supply schedules for cleanliness and any shifts in these schedules brought about by pollution. A maintained hypothesis of this study is that losses in welfare increase as pollution increases, even though the frequency of cleaning and _total cleaning_ expenditures as expressed by increasing monetary expenditures, in the marketplace, may not change.

The main policy implication of the study stems from our finding that soiling welfare losses can be relatively large. As we show, neglect of these losses could bias benefit/cost calculations toward inefficiently low levels of control.

The plan for the remainder of the paper is as follows. First, we explain how the demand and supply functions for household cleanliness can be used to estimate the change in consumer welfare due to pollution variations. Second, we discuss empirical methods and present results from estimating demand and supply functions. Following this, we provide (for Philadelphia and the Nation) estimates of consumer gains in welfare due to cleaner household environments that could be achieved through meeting the Federal primary and secondary standards for particulate matter. The major policy implications are then discussed in the final section.

Methodology

Welfare losses

A deterioration in air quality can shift the supply curve for household cleaniness to higher levels; in turn this can result in consumer and producer losses.[3] Empirical measurement of these losses depends upon the shapes of the demand and supply curves for household cleanliness, the extent to which the supply curve is shifted when pollution varies, and the manner in which the supply curve is shi-fted (for example, in a parallel fashion or, alternatively, in a multiplicative or rotational fashion).

The analysis presented in this section considers three hypothetical cases:

(1) A demand curve with constant unitary negative elasticity (that is, a rectangular hyperbole) combined with an increasing linear marqinal cost curve that shifts in a multiplicative or rotational fashion as pollution varies.

(2) A constant unitary elasticity demand curve combined with a constant marqinal cost curve that shifts in a parallel fashion as pollution varies.

(3) A demand curve that maintains a constant outlay for cleaning combined with an increasing linear marqinal cost curve that shifts in a parallel fashion as pollution varies.

These cases are examined because they agree with empirical estimates of demand curves for household cleanliness (presented in the next section) and provide interesting variations in the supply curves. To move ahead somewhat, a constant unitary elasticity demand curve or a demand curve that maintains constant outlays is used because empirical evidence provided in this paper indicates that expenditures on specific household cleaning tasks remain constant as pollution varies. On the cost or supply side it seems likely--based upon physical relationships described below--that the supply curve for cleanliness has a positive slope and is shifted in a multiplicative or rotational fashion as pollution varies (our case 1). But empirical evidence of supply curves is speculative and it seems prudent, therefore, to investigate the other two cases. As indicated below, welfare losses (or alternatively, benefits when pollution is controlled) under case 1 and case 2 are equal whereas losses in welfare estimated under case 3 are about twice the losses under cases 1 and 2. To help ensure that the estimates of benefits are not biased upward, the lower, more conservative estimates of case 1 are used to compare the benefits and costs of achieving Federal primary and secondary particulate standards.

Case 1

Figure 1 shows a hypothetical household income compensated demand curve, DD', and the marginal costs or supply curves $MC(P_1)$ and $MC(P_2)$ for household cleanliness at two different pollution levels, P_1 and P_2 respectively. It is assumed, for illustrative purposes only, that this is a representative household, that pollution doubles ($P_2 = 2P_1$), and that the household demand schedule for cleanliness has unitary negative elasticity. For the supply curve, it is assumed that the marginal cost schedule rotates in proportion to the ratio of the final and base pollution levels:

$$MC = a\,(P_f/P_b)^{\alpha}\,Q \qquad (1)$$

where

MC is marginal costs per unit of cleanliness;

P_f is the final level of pollution;

Pb is the base or reference level of pollution;

Q represents units of cleanliness; and

a and α are numerical parameters.

Also, for illustrative purposes only, it is assumed that a = 1. Thus at cleanliness level A (see Figure 1), the initial level of marginal costs, AB, would double to AH when pollution doubles.

The welfare loss to the consumer when pollution doubles is measured by area CBFC. This consists of CJFG, the higher private values for the consumed units of cleanliness, and JBF, the foregone satisfaction that the consumer had when pollution was less. Given the hypothetical demand and supply schedules illustrated in Figure 1, the consumer's welfare loss is approximately 70.7 percent of the original outlay (i.e., CBFC = 0.707 . OAB).[4] It is noteworthy that the loss occurs even though cleaning frequency and total market expenditures on cleaning remain unchanged. Using the changes in cleaning frequency and expenditures as measurable indicators of consumer loss, as previous studies have done, would show no measurable welfare loss in the example shown in Figure 1 because the differential in cleaning outlays is zero. Only when the demand curve for cleanliness is perfectly vertical (corresponding to a demand price elasticity for cleanliness of zero), will the loss in economic welfare (OBH in Figure 1 when pollution doubles) equal the increase in cleaning expenditure (OBH).

$MC(P_1)$ and $MC(P_2)$ in Figure 1 are the supply curves for P_1 and P_2 levels of air pollution, respectively. Imbedded in these supply curves are certain assumed technological and economic relationships for cleaning technologies. The shape and pollution-induced rotation of the supply curves can be logically deduced from these features.

For example, many, if not most, households supply their own cleaning labor at an increasing marginal opportunity cost. Thus, the household cleanliness supply curve is likely to be positively sloped. But in addition to having a positive slope, the cleanliness supply curve could also be concave upward under the reasonable assumption that a percentage change in cleanliness is proportional to a percentage change in cleaning costs.[5] However, a linear increasing marginal cost schedule is used because (1) welfare changes estimated by using linear schedules are nearly the same as those estimated with curvilinear schedules, and (2) the equations for estimating the change in consumer welfare are easily derived when linear schedules are used (see below).

The shift or rotation in the cleanliness supply curve is determined by the value for the parameter α in equation 1. The specific relationship expressed in equation 1 follows-directly from the plausible assumption that percentage change in cleaning effort, to achieve a given cleanliness level, is proportional to percentage change in relative pollution. For example, if $\alpha = 1$ then the marginal cost curve would rotate upward by 100 percent when pollution doubles.

A value for a larger (or smaller) than 1 would result in a more than (or less than) proportionate shift in the marginal cost schedule and, therefore, in larger (or smaller) changes in consumer welfare when pollution changes. A value for α of 1 and values both below and above 1 are supported by empirical evidence. These values and their empirical bases are discussed in the next section.

Cases 2 and 3

Other variations of the supply curve are a parallel shift in an increasing marginal cost curve as pollution changes and a parallel shift in a constant marginal cost curve as pollution changes. Unlike case 1 there does not seem to be a plausible basis or rationale that would support either of the two variations.[6] The first variation--a parallel shift in an increasing marginal cost curve--would provide an estimate of welfare loss (as pollution increases) that is twice the loss under case 1. The other variation--a parallel shift in a constant marginal cost curve--would result in the same welfare change as under case 1.[7]

Overall, there is little meaningful discussion of cleaning technologies in the technical literature. Thus, the final selection of a cleanliness supply function can only be based upon the degree of support from plausible assumptions and upon differences in results among alternative functional forms. Our preference, in terms of these criteria, is for the case 1 representation. It does appear to have a plausible basis. Compared to the other supply models considered here, the case 1 representation would, if anything, provide conservative estimates of cleanliness benefits from controlling particulate matter pollution.

Variations in Demand Curves,

Constant unitary elasticity demand curves, or a demand curve that maintains constant outlays for cleaning, have been used to explain the methodology, Empirical evidence, presented later in this paper, indicates that outlays on specific household cleaning tasks are invariant with respect to pollution over the observed pollution range. However, in an earlier study made in 1966, Michelson and Tourin [9] found a positive relationship between frequency of performing certain household cleaning tasks and particulate air pollution when they analyzed data gathered in Steubenville and Uniontown, Ohio. To our knowledge, no studies exist that show a negative relationship between cleaning frequency (or outlay) and variation in particulate pollution, although this is an acceptable economic outcome.[8]

Our concern is not to bias upward our estimates of the benefits that would result from reducing particulate matter to levels required by the Federal primary and secondary standards. The Michelson-Tourin result implies a demand curve for cleanliness (rotated about B) that would be to the northeast of BF in Figure 1. This in turn would lead to larger estimates of welfare changes than would the use of the demand curve BF, employed in this analysis. On this count also, our estimates of benefits from reducing particulates to the Federal primary and secondary standard would tend, if anything, to be conservative.

An Equation for Estimating Welfare Changes

If a marginal cost schedule as provided by equation (1) and a constant elasticity demand curve are assumed, the change in consumer welfare (ΔCW_{ij}) is given by[9]

$$\Delta CW_{ij} = -\Delta R_{ij}/R_{ij}\left[1 + (\Delta Q_{ij}/Q_{ij})/2\right] 2L_{ij} \qquad (2)$$

where

ΔR_{ij} = the change in the price of cleanliness for the i^{th} cleaning and maintenance task and the j^{th} household class;

ΔQ_{ij} = the change in the units of cleanliness for the i^{th} cleaning and maintenance task and the j^{th} household class;

L_{ij} = the base or reference outlay on the i^{th} cleaning and maintenance task by the j^{th} household class ($= X_{ij}/2 = R_{ij} \cdot Q_{ij}/2$); and

X_{ij} = the base or reference value of cleanliness associated with i^{th} cleaning and maintenance task by the j^{th} household class.

The two unknown expressions in equation (2), the percentage changes in price and quantity of cleanliness, are given by these expressions:

$$\Delta R_{ij}/R_{ij} = (P_{jf}/P_{jb})^{\alpha_i/2} - 1 \text{ and} \qquad (3)$$

$$\Delta Q_{ij}/Q_{ij} = (1/(1 + \Delta R_{ij}/R_{ij})) - 1 \quad . \qquad (4)$$

where

P_{jf} = final level of particulate pollution for the j^{th} household;

P_{jb} = base or reference level of particulate pollution for the j^{th} household; and

α_i = physical parameter derived from experimental data.

Equation (3) follows from the simultaneous solution of equation (1) and the unitary elasticity demand equation.[10] Equation (4) follows directly from the unitary elasticity demand equation ($X_{ij} = R_{ij} Q_{ij}$).

Empirical Estimates of Consumer Welfare[11]

Equations (2), (3) and (4) allow consumer welfare associated with household cleanliness to be estimated for specified changes in the level of ambient particulate matter. Implementation requires empirical estimation of the parameter a_i, empirical verification that frequency of household cleaning does not vary over the observed ranges of particulate matter, and estimation of base or reference expenditures on specified cleaning and maintenance tasks.

Estimating a

Five indoor and three outdoor cleaning and maintenance tasks were considered for analysis (see Table I). ideally, values Of α_i for each cleaning and maintenance task should be considered; however, a single set of estimates was derived and used repeatedly for each task: a low estimate of 0.56; a middle estimate of 1.0, and a high estimate of 2.0.

The estimates were derived from the technical literature. A thorough search revealed only two articles which could be used to provide values, namely, Beloin and Haynie [2] and Esmen [5]. The findings of Beloin and Haynie were used to derive the low (0.56) and middle (1.0) estimates for α_i. The high estimate (2.0) is based upon Esmen's results.

Estimating the Relationship between Frequency of Cleaning and Particulate Pollution

The data utilized in estimating frequency of cleaning functions were taken from a cross-sectional survey of 1442 households in the Philadelphia Standard tletropolitan Statisticai Area (SMSA).[12] The data consist of observations from each household on socioeconomic characteristics, attitudes towards household cleanliness, and the frequency with which household cleaning and maintenance tasks were performed. A pollution zone for each household was recorded. The mean pollution level of that zone was assigned to each household. All the socioeconomic characteristics, except the number of people in the household and number of children under 6 years of age, were converted to zero-one dummy variables.

Variables reflecting attitudes towards cleanliness, expressed as 13 zero-one dummy, variables were also developed for the analysis. Each household was assigned to an attitudinal cluster based on the household score for six cleanliness factors. The factors were determined by conducting factor analysis on household responses to 56 questions on attitudes, included in the cross-sectional survey. Assignment to one of the 13 attitudinal clusters was determined by finding households with similar factor scores.”

For the selected indoor and outdoor cleaning tasks, frequencies of performance for households conducting the tasks were regressed against socioeconomic characteristics, attitudes towards cleanliness, and household pollution levels. The proportion of explained variance (R^2), for cleaning frequency was less than 0.2 in all cases. Some of the independent variables had signs that contradicted a priori assumptions about the direction of the relationships. In essence, statistically significant relationships were not found. Consequently, it was concluded that the frequency of cleaning was not significantly different across households having different socioeconomic characteristics, attitudes, and pollution levels.[14]

Our findings allow three implications to be drawn on estimating changes in consumer welfare:

(1) It follows that if the supply schedule for cleanliness is a rotating linear schedule passing through the origin (case 1), then the demand curve for household cleanliness has unit negative' price elasticity. In other words, as the marginal costs or prices of cleanliness vary (as pollution changes), the total value and total outlays for cleanliness remain constant. Therefore, the demand and market prices for household cleaning and painting supplies will not be affected by changes in pollution levels, at least over the range of air pollution values examined in this analysis (61 to 133 ug/m^3, total suspended particulate). Households do not attempt to adjust to a dirtier environment by changing their cleaning outlays or habits. However, there is a welfare loss incurred by the households exposed to dirtier environment. This loss is the lower utility of having to live in a more polluted environment.[15]

(2) Since cleaning frequencies do not change, it is not necessary to assign households to different classes on the basis of cleaning behavior in order to estimate changes in consumer's welfare.

(3) Even though the regression analysis indicates no difference in behavior, it is, nevertheless, necessary to classify households by their initial pollution levels. _Ceteris paribus,_ households in more polluted areas face higher unit prices for cleanliness. They stand, therefore, to gain more from a reduction of air pollution toward the levels required by Federal standards.

Estimates of Welfare Gains

Table II presents a classification of households in the Philadelphia area by pollution zone. Application of Equation (2) requires an estimate of observed cleaning outlays (L_{ij}) by cleaning task (as indexed by i) and by pollution zone (as indexed by j). Table II presents the estimates for L_{ij} which are derived by applying the equation given in footnote b of the table. It is assumed that (1) the sample of 1,442 households is representative of the Philadelphia SMSA, and (2) the average unit cleaning and painting costs are the same across the four pollution zones.[16]

Estimates of consumer welfare gain for Philadelphia are presented in Part A of Table III for different values of a_i. The estimates, on the assumption that total suspended particulate is reduced to the Federal primary standard, range from $23.1 to $84.9 million per year, or from $16 to $57 per household annual ly. Aggregate welfare gains' for reducing particulates to the primary standard in 123 SMSA'S including Philadelphia, as shown in Part B of Table III, range from $858 to $3,227 million per year, or from $23 to $85 per household annually.[17] Gains or benefits from reducing particulates to the secondary standard are about twice as large.[18]

The estimated welfare loss function for Philadelphia is shown in Figure 2. It is noteworthy that the loss function is concave downward or, obversely, that the benefit function from less soiling is concave upward. Any household profiting by a reduction in pollution will experience benefits.occurring at an increasing rate as particulate pollution approaches background levels. This can be confirmed by substituting equations (3) and (4) into equation (2) and taking the derivative of ΔCW with respect to Pf for a given value of P_b when $P_f < P_b$. A second reason for the concavity is that an increasing number of households within a geographic area benefit as the pollution concentration standard is made more stringent.

At this point, it is necessary to digress and state two important additional qualifications to the analysis. The first is that estimates of the gains in consumer welfare utilize an estimate of cleaning expenditure by households actually performing the specified cleaning and maintenance tasks. However, as indicated in Table II, not all households performed the tasks. This is especially true for households in the high pollution zone where low income and less time for cleaning may constrain household behavior. Any gain from improvements in air pollution, which these non-spending households may incur, is not captured by the estimating process outlined in this paper. However, the households may be willing to pay to live in less-soiled houses if pollution is reduced. One approach to obtaining estimates is to conduct direct interviews. Since this study does not conduct direct interviews, the estimates presented in this paper are likely to be conservative.

The second qualification pertains to labor costs where householders actually performed their own maintenance and cleaning. The estimates in reference [3], the basis for the estimated total expenditure in Table II and, therefore, the basis for the estimates of welfare gain in Table III, include labor costs only for services that are contracted (roughly 25 percent of all services). The remaining services were performed by “do-it-yourself” households for which the reported costs include only material expense. Including labor costs at estimated contract rates would increase welfare gains by about a factor of four. However, there is uncertainty surrounding the estimated contract rates since they are based on relatively small samples (see reference [3]). Furthermore, contract rates may not be the appropriate prices for valuing "do-it-yourself" labor. Our preference is to be conservative in estimating welfare gains; and, therefore, the original cost estimates from reference [3] are used without adjustment.

Implications

The major policy implication of the analysis is that the neglect of welfare losses from soiling and the application of inappropriate measurement methodologies could result in the implementation of inefficient particulate controls. To demonstrate this point, we have assembled some benefit and cost estimates at the national level for controlling particulate matter pollution (shown in Table IV). With soiling benefits included, the largest net benefit ($2,109 million per year) occurs as the secondary standard is approached (60 ug/m^3).[19] On the other hand, without estimates for soiling benefits, net benefits for controlling particulate matter are negative over the range of controls considered in Table IV.

Obviously, before rigorous policy conclusions on the efficiency of particulate standards can be drawn, it would be necessary to undertake refined regional cost/benefit analysis. Nonetheless, the important point is that neglect of soiling benefits or their incorrect measurement could adversely influence policy choices.

As a means of overcoming these problems, the contribution of this paper has been to demonstrate an appropriate methodology for estimating benefits from less soiling. For further refinements in the benefit methodology, better information is needed on the value for a_i, on the shape of the marginal cost of cleanliness curve, and on the manner in which the curve shifts as pollution changes.

APPENDIX

Consider the following figure:

where L = OAB, X = 2L, and $k = (P_f/P_b)^{\alpha}$

$$\text{Area OBF} = \text{CBFG} = d(e_1 + e_2/2) \tag{1}$$

where $d = (2Lka)^{\frac{1}{2}} - (2La)^{\frac{1}{2}}$

$e_1 = (2L/Ka)^{\frac{1}{2}}$

$e_2 = (2L/a)^{\frac{1}{2}} - (2L/Ka)^{\frac{1}{2}}$

On substitution into equation (1)

$$\text{CBFG} = ((k-1)/k^{\frac{1}{2}})L \tag{2}$$

Then, assuming Pf = 2Pb and $\alpha = 1$:

CBFG/L = .707

This derivation of CBFB/L treats BF as a straight-line segment. Alternatively, by integrating under R:

CBFG/L = ln(k) = .693 (assuming P_f = 2Pb and $\alpha = 1$)

FOOTNOTES

* William D. Watson is an economist with the U.S. Geological Survey, Reston, VA. John A. Jaksch is manager and senior research associate with Rogers, Golden, and Halpern, 1920 Association Drive, Reston, VA. When this research was completed, Jaksch was associated with the Environmental Protection Agency, Corvallis, Oregon. The authors would like to express their appreciation to several people who reviewed or assisted in earlier drafts of this paper: Herbert H. Stoevener, Department of Agricultural Economics, Virginia Polytechnic Institute, Blacksburg; Hyrick freeman, Department of Economics, Bowdoin College, Brunswick, Maine; Ronald Cummings and H.A. Burness, Department of Economcis, University of New Mexico, Albuquerque; and Ronald Sutherland, Los Alamos Scientific Laboratory, New Mexico. The views expressed in the paper are solely those of the authors.

1 An ideal control level, in terms of optimizing allocative efficiency, would be achieved when marginal costs of control equal marginal benefits obtained as a result of the control.

2 See, for example, [1], [3], [4], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [23], and [24].

3 Air quality can enter the consumer's utility function directly or be treated as a production function shifter for goods that do enter the utility function. The second procedure is followed in this paper. Tolley [25, pp. 4-8] has derived the first order conditions for this procedure and shown that they are analagous to the conditions under which firms maximize profit when environmental quality affects production.

4 See appendix for derivation.

[5] This proportional relationship would be similar to the double logarithmic form between costs and attributes typically found in hedonic studies.

[6] As a demonstration of concepts, Tolley [25, p. 7] derived an equation for estimating welfare changes when an increasing marginal cost schedule shifts in a parallel fashion as pollution changes. Tolley [25, p. 7] also suggested the use of a constant marginal cost schedule for calculating losses associated with cleanliness but did not provide any reasons for his selection.

[7] Details are available from the authors upon request.

[8] For example, if the demand curve in Figure 1 (BF) was rotated to the left about point 8, then when pollution doubles, outlays for household cleanliness would be less than they were before the rotation.

[9] With additional substitution and manipulation, equation (2) can be written as $\Delta CW_{ij} = -[\Delta R_{ij}(Q_{ij} + \Delta Q_{ij}) - \Delta R_{ij}\Delta Q_{ij}/2]$ which in Figure 1 is the area -(CJFG + JBF). Alternatively, the immediately preceding expression for ΔCW_{ij} can be thought of as having been derived from the application of area formulas to Figure 1 (see Appendix). Equation (2) would then follow from an algebraic rearrangement of this expression.

[10]
$$X_{ij}/Q_{ij} = a(P_{jF}/P_{jb})^{\alpha_i} Q_{ij}$$
$$Q_{ij}^2 = X_{ij}/a(P_{jf}/P_{jb})^{a_i}$$
$$Q_{ij} = (X_{ij}/a(P_{jf}/P_{jb})^{\alpha_i})^{1/2}$$
$$R_{ij} = a^{1/2}X_{ij}^{1/2}$$
$$\Delta R_{ij} = a^{1/2}X_{ij}^{1/2}((P_{jf}/P_{jb})^{\alpha_i/2} - 1)$$

$$\Delta R_{ij}/R_{ij} = (P_{jf}/P_{jb})^{\alpha_i/2} - 1$$

11 An abbreviated account of our estimating procedures follows. Reference [26] provides a more complete description of methods and may be obtained from the authors.

12 The questionnaire and sampling procedures are discussed in Booz, Allen, and Hamilton [3]. Analysis of these data was also undertaken by Boot, Allen, and Hamilton [3]. But their analysis was incomplete and had several statistical deficiencies [23]. The current study uses only the original data and performs statistical analyses on the data.

13 Reference [26] provides a more complete description and discussion of the analytical procedures used to do this.

14 Similar results were obtained by Ridker [19] when he performed an almost identical analysis of data gathered in 1965 from a smaller set of households in Philadelphia.

15 In other words, as illustrated in Figure 1, we assume that households prefer more cleanliness to less. There is, on the other hand, 'the possibility that there are some households who may take "no action" because they really don't care. If air quality deteriorates, they don't clean more and their utility is not affected even though the average level of cleanliness is lower. We assume that such households do not exist and that, in fact, a reasonable assumption is that higher levels of cleanliness are preferred to less.

16 The analytical results on cleaning behavior indicate that the frequency of task performance is not significantly different across pollution zones. Therefore, a constant value for frequency, like a constant value for unit costs. cancels out on the right-hand-side of the equation for I

[17] See Table III, footnote b, for the assumptions utilized in making these estimates.

[18] Estimates foi each individual SMSA are available from the authors.

[19] This assumes $\alpha_i = 1.0$. Suiprisingly, values of α_i equal to 0.56 and 2.0 also yield maximum net benefits at 60 ug m^3 (all other estimates used within the analysis being held constant).

REFERENCES

1. H. Beaver, "Committee on Air Pollution Report," Her Majesty's Stationery Office, London, (1954).

2. N.J. Beloin and F.H. Haynie, Soiling of building materials, Journal of the Air Pollution Control Association, 25 (4), 339-403 (1975).

3. Booz, Allen and Hamilton, "Study to Oetermine Residential Soiling Costs of Particulate Air Pollution," U.S. Department of Health, Education, and Welfare, Environmental Health Service, National Air Pollution Control Administration, Raleigh, North Carolina, Contract No. CPA 22-69-103 (1970).

4. Department of Trade and Industry, "An Economic and Technical Appraisal of Air Pollution in the United Kingdom," Program Analysis Unit, Her Majesty's Stationery Office, London, (1972).

5. N.A. Esmen, A direct measurement method for dustfall, Journal of the Air Pollution Control Association, 23(1); 34-36 (1973).

6. A.C. Jones, Studies to determine the costs of soiling due to air pollution: an evaluation, in: "Economics of Air and Water Pollution," (W.R. Walker, Ed.), Virginia Polytechnic Institute, Water Resources Center, Blacksburg, VA, (1969).

7. R.I. Larsen, Air pollution damage to paint, American Paint Journal, 42, 94-109 (1957).

8. B. Liu and E.S. Yu, "Physical and Economic Damage Functions for Air Pol lutant by Receptors," Environmental Protection Agency, Office of Research and Development, Washington, D.C., EPA-600/5-76-011 (1976).

9. I. Michelson. and B. Tourin, Comparative method for studying costs of air pollution, Public Health Reports 81(6), SOS-511, (1966).

10. ______________, "The Household Costs of Living in Polluted Air in the Washington, D.C. Metropolitan Area," Report presented to U.S. Public Health Service Conference on Air Pollution Abatement in the Washington, D.C. Metropolitan Area, at Washington, O.C., (December 12, 1967).

11. ______________, "Report *on* Study of Validity of Upper Ohio River Valley to Washington, D.C. Area," PHS Contract PH 27-68-22, Environmental Health and Safety Research Associates, New Rochelle, NY, (1967).

12. I. Michelson and B. Tourin, "Household Costs of Air Pollution--Control of Air Pollution Costs Less than Living in Polluted Air," Draft report, PHS contract PH 86-67-221, Environmental Health and Safety Research Associates, New Rochelle, NY, (1967).

13. ________________________, "The Household Costs of Living in Polluted Air versus the Costs of Controlling Air Pollution in the Twin Kansas Cities Metropolitan Area," Report to the U.S. Public Health Service Conference on Air Pollution Abatement in the Twin Kansas Cities Metropolitan Area, 1968, Environmental Health and Safety Research Associates, New Rochelle, NY (1968).

14. ________________________, "The Household Costs of Living in Pollution versus the Costs of Controlling Air Pollution in the Upper Ohio River Valley," Report to the U.S. Public Health Service, National Center for Air Pollution Control, Environmental Health and Safety Research Associates, New Rochelle, NY (1968).

15. ________________________ "Report on: The Household Costs of Air Pollution in Connecticut," Report'to the Connecticut State Department of Health, Environmental Health and Safety Research Associates, New Rochelle, NY (1968).

16. R.L. Naraganan and B. Lancaster, Household maintenance costs and particulate air pollution, Clean Air 7(1), 10-13 (1973).

17. J.J. O'Connor, "The Economic Cost of the Smoke Nuisance to Pittsburg," Mellon Institute of Industrial Research and School of Specific Industries, University of Pittsburg (Smoke Investigation Bulletin No. 4), Pittsburg, PA (1913).

18. J.H. Parker, Does smoke abatement pay?, Heating, Piping, and Air Conditioning 18(4), 80-84 (1946).

19. R.G. Ridker, "Economic Costs of Air Pollution: Studies in Measurement," Frederick A. Praeger, New York (1967).

20. R.G. Ridker and W.D. Watson, "To Choose a Future, Resource and Environmental Consequences of Alternative Growth Paths," Johns Hopkins University Press for Resources for the Future, Baltimore, MD (1980).

21. U.S. Bureau of the Census, "County and City Data Book, 1972," U.S. Government Printing Office, Washington, D.C. (1973).

22. U.S. Environmental Protection Agency, "The National Air Monitoring Program: Air Quality and Emissions Trends Annual Report," Volume II, EPA-45071-73-001-b (1973).

23. T. Uaddell, "The Economic Damages of Air Pollution," Washington, D.C., Environmental Protection Agency, Office of Research and Development, EPA 600/5-74-012, Washington, D.C. (1974).

24. H.S. Wohlers and M. Feldstein, "Corrosion Aspects of Air Pollution in the San Francisco Bay Area: Exterior Paint," Bay Area Air Pollution Control District, San Francisco, CA (No date).

25. G.S. Tolley, The resource allocation effects of environmental policies, in "Benefit-Cost and Policy Analysis, 1973," (Haveman, Harberger, Lyman, et al, Eds.), Aldine Publishing Company, Chicago, IL (1974).

26. W.D. Watson and J.A. Jaksch, "Household Cleaning Costs and Air Pollution," Discussion Paper D-40, Resources for the Future (1978).

Table 1. Cleaning and Maintenance Tasks[a]

Indoor	Outdoor
Painting walls and ceilings	Painting walls
Wallpapering	Painting trim
Washing walls	Washing windows
Washing windows	
Cleaning Venetian blinds	

[a] The Boot, Allen, and Hamilton study [3] evaluated 15 indoor and 12 outdoor tasks. From these, the eight tasks shown in this table were selected as those most likely to be affected by suspended particulates. The select ion criteria were based upon a literature review, which indicated that smooth surfaces are more likely to be noticeably soiled by particulates. From the original list of 15 indoor tasks, floor cleaning was left out because particulate soiling is probably small compared to other types of soiling. Furniture shampooing, cleaning curtains and draperies, and replacing filters in furnaces and air conditioners were left out because no documented evidence could be found which showed that they were affected by particulates. General outdoor maintenance, such as that performed on screens, awnings, and outdoor furniture, was also excluded because evidence of particulate soiling impacts was not uncovered. Cleaning and waxing of cars were eliminated because road dust and dirt probably account for most soiling.

Table II. Pollution, and Cleaning and Painting Expenditures for Philadelphia

Pollution zone	Average particulate level (micrograms per cubic meter)	Percent of households in zone J out of all households'	Percent of households in zone performing tasks[a]					Annual expenditure of L_{ij} (millions of 1971$)[b]				
			Painting walls & ceilings	Wall papering	Washing windows	Washing walls	Cleaning venetian blinds	Painting walls & Ceilings	Wall Papering	Uashing walls	Washing windous	Cleaning venet ian bl inds
A. Indoor tasks												
1	61											
2	87	17.3	76.6	36.9	97.2	42.7	34.0	28.2	23.4	9	8.6	3.2
3		23.0	72.0	45.4	97.9	41.3	48.2	12.9	14.0	4.4	4.0	2.2
4	112	10.0191	67.9	43.1	97.0	45.8	62.5	10.1	11.1	3.6	3.7	2.4
	133		59.0	52.6	98.0	37.1	59.4	4.8	7.5	2	1.7	1.2
					Total Expenditure or TE_i:[c]			56	56	19	18	9
B. Outdoor Tasks			Painting wails	Painting trim	Washing windows			Painting walls	Painting trim	Washing windows		
2	61	47.3	38.6	66.5	89.5			20.2	24.8	8.6		
3	1i87	23.019.1	11.4	54.5	86.3 89.5			7.2 2.4	12.4 8.2	4.2		
										3.3		
4	133	10.6	10.4	55.0	89.3			1.2	4.6	1.9		
					Total Expenditure or TE_i:[c]			31	50	18		

a Source is Booz, Alien, & Hamilton [3]

b $L_{ij} = (PH_j \cdot PHT_{ij} / \sum_j PH_j \cdot PHT_{ij}) \cdot TE_i$

where PM_j is percent of households in zone J out of ail households

PHT_{ij} is percent of households in zone J performing task I

TE_i is total expenditure for task I

Source is Boor, Alien, and Hamlition [3] for 5 of the tasks. Costs for the remaining 3 were derived as follows: wall papering costs are assumed to equal inside painting costs, venetian blind cleaning costs are assumed to equal one-half of window cleaning costs and costs of cleaning windows outside are assumed to equal costs of cleaning windous inside.

Table III. Welfare Gain Obtained by Reducing Particulate Pollution

	Total Gain (millions of 1971$)[a] Primary Standard	Secondary Standard	Gain per household (1971$) Primary Standard	Secondary Standard
A. Philadelphia				
$\alpha_i = .56$	$ 23.1	$ 43.9	$16	$ 30
$\alpha_i = 1.0$	41.4	79.2	28	53
$\alpha_i = 2.0$	84.9	165.2	57	112
B. 123 SMSA's including Philadelphia[b]				
$\alpha_i = .56$	$ 858	$1466	$23	$ 39
$\alpha_i = 1.0$	1547	2656	41	70
$\alpha_i = 2.0$	3227	5656	85	149

[a] For the primary standard, welfare gains are obtained by reducing 1970 measured particul tate levels to 75 ug/m^3. Similarly, for the secondary standard, welfare gains are obtained by reducing particulate from measured levels to 60 ug/m^3. The welfare gain in going from the primary to the secondary standard is the difference between the primary and secondary gains.

[b] Estimates for other SMSA's are made by assuming:

(1) Total expenditures for each task in other SMSA's equal expenditures per household for each task in the Philadelphia region times the number of households in the other SMSA's. The numbers of households in each SMSA are taken from reference [21].

(2) The fractional distribution of total expenditure across pollution zones (i.e., L_{ij}/TE_i) is the same as that indicated in Table II for Philadelphia.

(3) The distribution of particulate in any other SMSA relative to its mean particulate level is the same as in the Philadelphia region: $AP_{jk} = (AP_{j,Phila.}/MEAN_{Phila.})MEAN_k$ where AP_{jk} is the average particulate reading in the jth zone and kth SMSA, and $MEAN_k$ is the annual geometric mean for suspended particulates in the kth SMSA. Source of $MEAN_k$ is the U.S. Environmental Protection Agency [22].

Table IV. Benefits and Costs at the National Level from Controlling Total Suspended Particulates

	Benefits (millions of 1971$)				Annual Control cost (millions of 1971$)[e]	Annual Net Benefits (millions of 1971$)	Annual Net Benefits Excluding Soiling (millions of 1971$)
Standard[a] (ug/m^3)	Less Soiling[b]	Health[c]	Less Material Damage[d]	Total			
175	613	540	36	1189	1515	-326	-939
60	2656 1547	21890	127 182	5538 3564	2551 3429	2109 1013	-547 -534
55	3167	2700	200	6067	4754	1313	-1854

[a] Uniform standard applicable to all regions.

[b] Source is this study.

[c] Assumptions are as follows: average annual concentration of 110 ug/m^3 with control at levels prevailing in the 1965-70 period (i.e., before EPA came into existence); no benefit at 110 ug/m^3; benefits increase linearly between zero and $2.7 billion [23] as the concentration declines until a standard of 60 ug/m^3 is reached.

[d] The assumptions are the same as for the health benefits, except the maximum benefit is reached when the particulate concentration reaches 55 ug/m^3. Source of the $200 million estimate is [23].

[e] Annual control expenditures are costs of reducing particulate concentrations below 110 ug/m^3. These estimates include costs for electric utilities, industrial sources, and residential and commercial fuels combustion (see [20]).

FIGURE CAPTIONS

Figure 1. Case 1: Producer's loss is zero since OFG equals OBC; therefore, consumer's loss equals CBFG (or equivalently OBF). Initial cleaning outlays, OAB, equal final cleaning outlays OEF.

Figure 2. Welfare loss function for household soiling from suspended particulates in Philadelphia.[a]

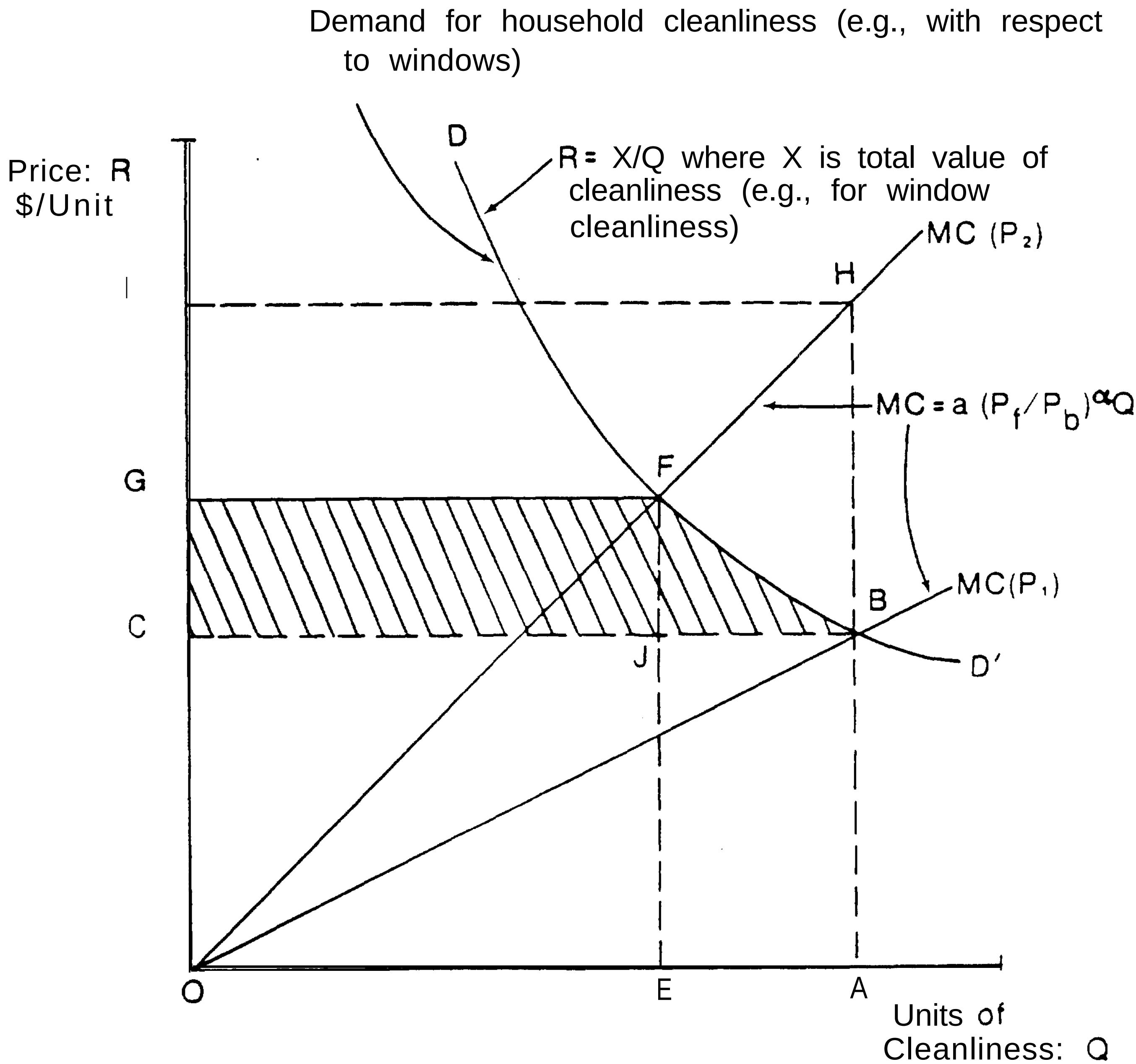

Demand for household cleanliness (e.g., with respect to windows)
Price: R
$/Unit
D
R = X/Q where X is total value of cleanliness (e.g., for window cleanliness)
MC (P_2)
H
I
MC = a $(P_f/P_b)^{\alpha}Q$
F
G
MC(P_1)
B
C
J
D′
O
E
A
Units of Cleanliness: Q

Figure 1

Table IV. Benefits and Costs at the National Level from Controlling Total Suspended Particulates

Standard[a] (ug/m^3)	Benefits (millions of 1971$) Less Soiling[b]	Health[c]	Less Material Damage[d]	Total	Annual Control cost (millions of 1971$)[e]	Annual Net Benefits (millions of 1971$)	Annual Net Benefits Excluding Soiling (millions of 1971$)
175	613	540	36	1189	1515	-326	-939
60	2656 1547	1890	127 182	5538 3564	3429	2109 1013	-547 -534
55	3167	2700	200	6067	4754	1313	-1854

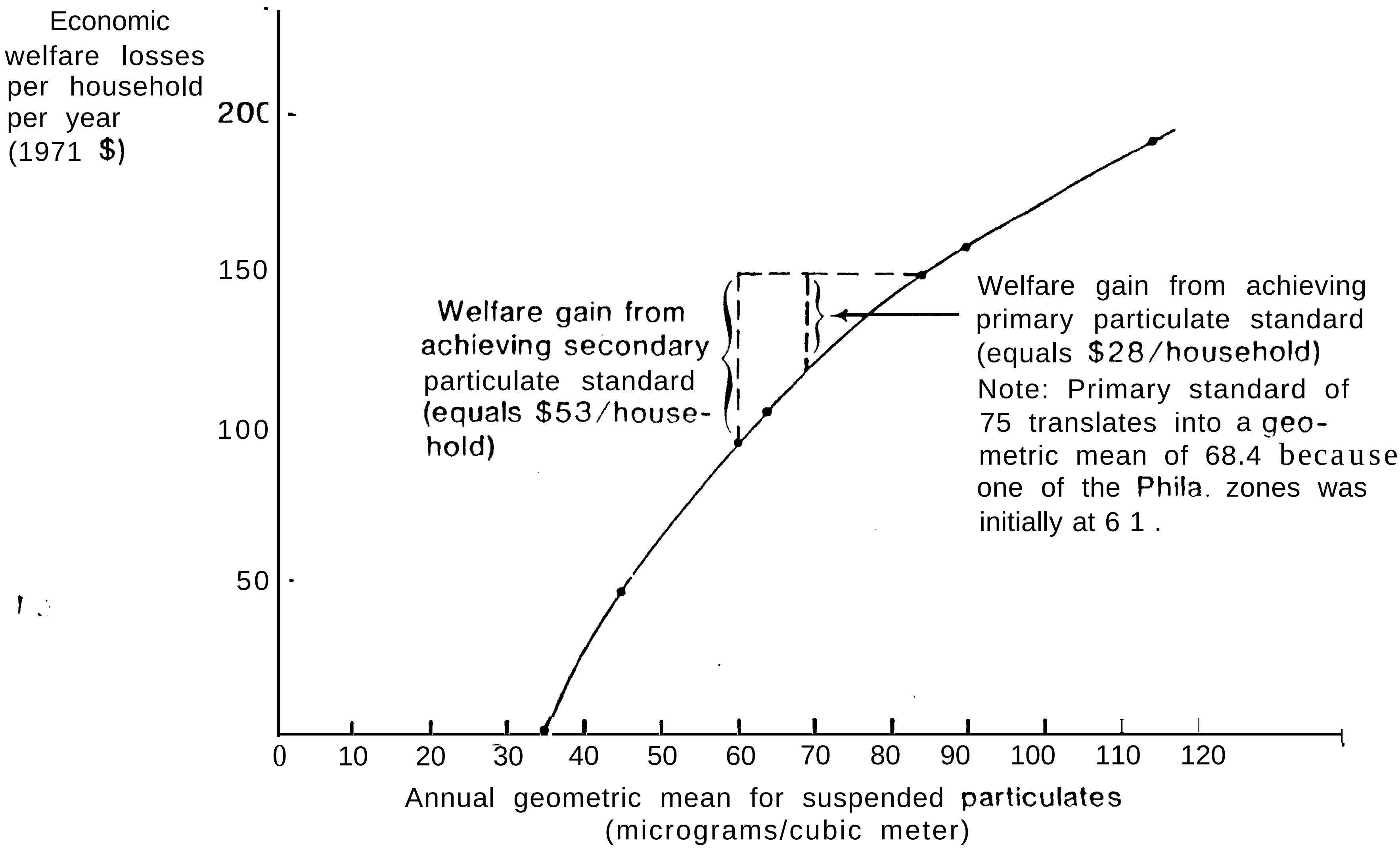
[a] Uniform standard applicable to all regions.

[b] Source is this study.

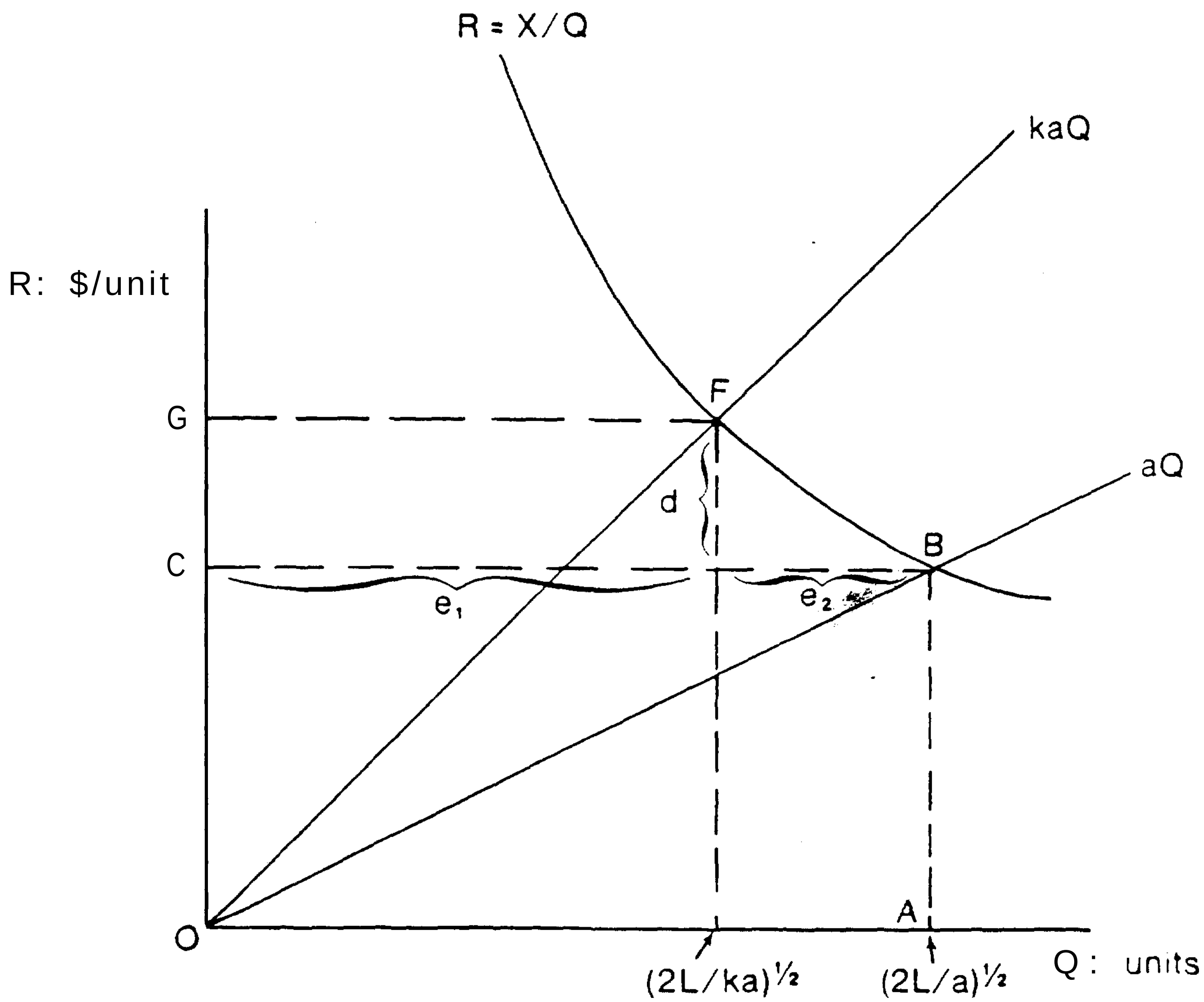
[c] Assumptions are as follows: average annual concentration of 110 ug/m^3 with control at levels prevailing in the 1965-70 period (i.e., before EPA came into existence); no benefit at 110 ug/m^3; benefits increase linearly between zero and $2.7 billion [23] as the concentration declines until a standard of 60 ug/m^3 is reached.

[d] The assumptions are the same as for the health benefits, except the maximum benefit is reached when the particulate concentration reaches 55 ug/m^3. Source of the $200 million estimate is [23].

[e] Annual control expenditures are costs of reducing particulate concentrations below 110 ug/m^3. These estimates include costs for electric utilities, industrial sources, and residential and commercial fuels combustion (see [20]).



[a] Assumes $\alpha = 1$ and a background level for suspended particutes of 35 micrograms per cubic meter. Total welfare losses can be estimated by multiplying unit losses by the number of housing units in Philadelphia (for example, 1,480,200 in 1970).


R = X/Q
kaQ
R: $/unit
F
G
d
aQ
C
B
e1
e2
A
O
(2L/ka)½
(2L/a)½
Q: units